Vadim O. KITIKOV
Republican Unitary Enterprise «Scientific and Practical Centre of the National Academy of Sciences of Belarus for Agriculture Mechanization», Minsk, Republic of Belarus
e-mail: kitsikau@tut.by
Вадим Олегович КИТИКОВ
Республиканское унитарное предприятие «Научно-практический центр Национальной академии наук Беларуси по механизации сельского хозяйства»

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BELARUS AND POLAND IN THE CONTEXT OF THE WORLD MILK PRODUCTION

Summary

A comparative analysis of milk production in Poland and Belarus has been completed. There have been analyzed the basic tendencies of modern development of the dairy industry and offered upcoming trends in innovative modernization of milk production processes. On the basis of the analysis of trends in world production of milk and new scientific knowledge about the biosynthesis of milk, there is provided a conceptual approach to the design of equipment for machine milking, considering the relationship of technical and physiological parameters. A new method for the analysis of energy consumption in the production of milk has been suggested.
***Key words**: machine milking, physiologically relaxed process, milking equipment, costs per unit*

BIAŁORUŚ I POLSKA W KONTEKŚCIE ŚWIATOWEJ PRODUKCJI MLEKA

Streszczenie

Przeprowadzono analizę porównawczą produkcji mleka w Polsce i na Białorusi. Przeanalizowano podstawowe tendencje rozwoju współczesnego mleczarstwa na świecie i na tej podstawie zaoferowano nowatorską modernizację procesów produkcji mleka. Na podstawie analizy światowych tendencji w produkcji mleka i nowej wiedzy naukowej o biosyntezie mleka, podano koncepcję projektowania urządzeń do doju maszynowego, z uwzględnieniem parametrów technicznych i fizjologicznych. Zasugerowano nową metodę analizy zużycia energii w produkcji mleka.
***Słowa kluczowe**: dój maszynowy, proces zrelaksowany fizjologicznie, urządzenia do doju, koszty jednostkowe*

БЕЛАРУСЬ И ПОЛЬША В КОНТЕКСТЕ МИРОВОГО ПРОИЗВОДСТВА МОЛОКА

Резюме

Выполнен сравнительный анализ производства молока в Польше и Беларуси. Рассмотрены основные тенденции современного развития молочной отрасли и предложены перспективные направления инновационной модернизации процессов производства молока. На основе анализа тенденций в молочно-товарном производстве и новых научных знаний в биосинтезе молока, предложен концептуальный подход к проектированию оборудования для машинного доения коров, с учетом взаимосвязи технических и физиологических параметров. Предложена новая методика для анализа энергозатрат при производстве молока.
***Ключевые слова**: машинное доение, физиологически щадящий процесс, доильное оборудование, удельные затраты*

1. Introduction. Global trends in production and consumption of milk

In nature, milk has no product of equal biological value. It consists of 250 substances important to a human being, required for normal metabolism (proteins, fats, carbohydrates, minerals, vitamins). Due to the fact that the biological norm of milk and milk products for a human being equals to 380 kg/year, the potential volume of world consumption should be at least 2 billion tons/year, which is three times higher than the actual volume of milk production (0.71 billion tons/year). According to the United Nations (UN), for 2025 the production of milk should be increased by at least 50%: for the growing needs of the population of the Earth, as well as an effective means to combat hunger in developing countries. Commercially, the dairy products are a commodity easily selling on the market, but the global export of this product is only 46 million tons/year, which is 3% of the needs of those countries which do not produce milk in sufficient volumes [1, 2]. It should be noted that the milk export from Poland and Belarus to the other countries amounts to 17% of global exports.

Thus, it can be concluded that due to the fact that the global dairy market is very far from its saturation in the countries, which have favorable natural and production conditions, the improvement of the dairy industry is relevant, scale important task aimed at the material and human development of the world community as a whole.

2. Case study. Characteristics of the dairy industry in Poland and Belarus

The most important factor for sustainable development of dairy farming is natural and climatic conditions for the production of feed. The optimum relationship of the temperature and humidity for specific areas is defined quantitatively by the hydrothermal coefficient:

$$k_{\Gamma} = \frac{10R}{\sum_{i=1}^{n} \overline{T_i}}, \quad (1)$$

where R – total precipitation, penetrating into the soil during the growing season, consisting of n days, mm; n – the number of days, in which the average daily temperature exceeds 10 °C; T_i – the average daily temperature on the i-th day,°C, $i=1,...,n$.

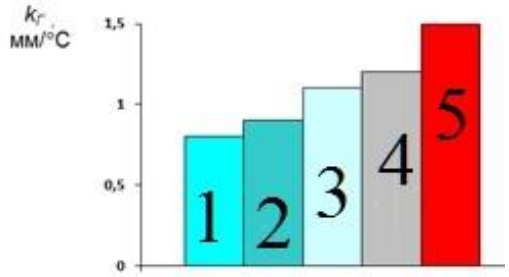

Fig. 1. Hydrothermal area ratio: 1 – France, 2 – Germany, 3 – UK, 4 – Poland, 5 – Belarus
Rys. 1. Współczynnik hydrotermalny dla poszczególnych terenów: 1 – Francja, 2 – Niemcy, 3 – W. Brytania, 4 – Polska, 5 – Białoruś

It is known that for the production of milk those territories are favorable where the hydrothermal factor varies in the range of $\leq 1{,}4$ $k_Г \leq 1{,}6$ [5]: a relatively large amount of rainfall and mild temperatures contribute to the maintenance of moisture in the topsoil that is necessary for effective growth of green stalked feed. Poland and Belarus as geographical neighbors have good conditions for the development of dairy farming, since for them $k_Г$ = 1.4-1.5 (Fig. 1).

Another favorable factor for the development of dairy farming in our countries is the high scientific potential of 10 specialized research organizations and 4 agricultural universities in Belarus and more than 20 research centers and agricultural universities in Poland.

Considering the generally favorable climatic conditions, high industrial and scientific and technical potential, as well as the global dairy products shortage, it can be concluded that in the future, the dairy farming in Poland and Belarus should be a priority for the development of the agriculture.

Table 1. Production of milk per inhabitant, 2015
Tab. 1. Produkcja mleka na 1 mieszkańca w 2015 r.

Country	kg/year
New Zealand	3400
Ireland	1200
The Netherlands	700
Belarus	**700**
Poland	**350**
Germany	350
USA	280
UK	250
Russia	220

Milk production in Poland and Belarus has now reached high enough quantitative results: 10.6 and 6.7 million tons of milk/year, respectively. Average milk yield per cow amounts to 5.6 and 5.1 tons/year respectively. According to official figures, Poland is 16th and Belarus takes the 21th place in the world in terms of growth in milk production [4]. According to the specific volume of milk produced per 1 inhabitant the indexes are also high: 350 kg/year in Poland and the 700 kg/year in Belarus (Table 1).

However, there are certain differences between the dairy industry in Poland and Belarus: the production capacity of farms and breed characteristics of milking herd (Table 2), as well as regulatory and technological base. Milking herd in Belarus is concentrated on large dairy farms (with more than 300 cows); in Poland the production is relatively small-scale (on the average less than 40 cows per farm). Therefore, from a scientific perspective the study of the scale factor in the production of raw milk for various purposes (cheese, powdered milk and other final milk products) represents a mutual interest.

Currently, both in Belarusian and Polish cattle breeding there are going processes of dairy cattle's holsteinization [1, 3], but in Belarus, about half of the dairy herd represents a regional black-and-white breed (Table 3).

With regard to the regulatory and technological base, in Poland there are applied the legislative instruments of the European Union (acquis communautaire), relating to the milk production and processing. In Belarus there are applied the Technological Regulations, uniform for countries of the Customs Union (Belarus, Russia, Kazakhstan).

Despite some advances in the dairy industry, Poland and Belarus have specific milk production indicators, which do not allow, at the moment, to ensure the level efficiency of production, comparable with those countries that are leading in the milk exportation. Thus, the specific volume of milk produced from the area of farmland, amounts to 80 and 78 tons/100 ha, respectively (Table 2), which is 2 times lower than, for example, in Germany, although the importance of hydrothermal factor for our territories is more preferable (Figure 1).

Table 2. Production of milk based on 100 hectares of farm land
Tab. 2. Produkcja mleka przypadająca na 100 ha użytków rolnych

Country	t/100 ha
Poland	**80**
Belarus	**78**
France	85
UK	94
Germany	160
The Netherland	180

Thus, Poland and Belarus, with some distinctive features, have similar natural conditions of production and export opportunities for the dairy industry, as well as common scientific and technical challenges associated with an increase of the competitive ability of milk. Close mutually beneficial scientific and technical cooperation between the two countries will speed up the solution of these problems.

To solve the problems of increase in efficiency of dairy industry there is necessary first of all to provide a significant reduction in the cost per unit of milk production.

The reasons of high cost per unit are due, as a rule, to a large share of hand work, low-comfortable conditions of cattle management, excessively traumatic processes such as machine milking, characterized by a high incidence of mastitis with cows, reducing milk production, which does not allow to exploit the genetic potential of the breed.

An analysis of the dynamics of the dairy sector development led to the conclusion that improving milk production processes as a result of simple upgrade (for example, the replacement of equipment with the new one) is not possible. This essential problem now can be solved only by means of innovative modernization, which will allow for a significant reduction in overall costs and achieve a high level of competitiveness of production.

Table 3. Characteristics of dairy cattle breeding in Poland and Belarus
Tab. 3. Charakterystyka hodowli bydła mlecznego w Polsce i na Białorusi

	Number of dairy farms			Number of cows		Dominating dairy cows breed
	Totally (thousand)	Public sector (%)	Private sector (%)	Totally (mln)	On 1 farm (animals)	
Poland	60,5	<5	>95	2,3	38	Holstein Friesian (Polish) – 85%
Belarus	4,3	>95	<5	1,5	310	Holstein Friesian (Belholstein) – 50% Belarusian black-and-white – 50%

The author believes that innovative modernization of the dairy industry can be achieved through the involvement of new knowledge developed in molecular biology, physiology and genetics, which will be the basis for the creation of effective, physiologically relaxed processes in the milk production. Let us illustrate the idea of innovative modernization of the production process by the example of cows' machine milking.

3. The innovative process of milk production modernization (in the context of milking process)

Hard mode of using the milking equipment does often result in injury to the animals. The consequence is a reduction in milk productivity and, most importantly - a high incidence of cow mastitis (sometimes up to 30% of the herd for a year). It is known that cows recover from mastitis, have a reduced immune response, which adversely affects their lactation performance and milk quality [6-13]. Since the level of the cost per unit is largely determined by the lactation performance of cows (the quantity and quality of raw milk), and since only in the process of milking the direct contact of the udder and working elements of the machine milking takes place, the imperfection of such process brings to ought the efforts of the farm team. In this regard, without diminishing the importance of a balanced feeding, maintenance of the animals in the dairy barn and animal zoo-veterinary preventive treatment, we can say that currently, it is machine milking process that plays a key role in increasing the lactation performance, since if the machine milking process and milking equipment are not effective (injure cows), the genetic potential and pre-milking cattle maintenance conditions are not critical.

The innovative modernization process of milking is carried on thanks to the latest scientific knowledge developed in allied disciplines such as genetics and molecular biology. Because of the importance of the aforesaid, we shall cite some well-known scientific principles that characterize the hormonal nature of lactation:

- the alveolar milk can *only* flow into the udder cistern (which is 80% of a single milk yield) when the blood of animals contain oxytocin, hormone which acting on the smooth muscles of the alveoli, causes them to shrink, "pressing" milk into the ducts and udder cistern. Action period of oxytocin equals to 4-5 minutes;
- the stress during milking is accompanied by release of adrenaline into the blood which blocks the action of oxytocin and thus complicates the lactation;
- the first portions of the udder's milk contain less than 1% fat, the last portion of the alveolar milk contains 15-20% fat;
- the completeness of dry alveolar milking not only provides the maximum milk yield and high fattiness of milk, stimulates the secretion of the lactation increasing the lactation period.

The implementation of these statements at the development of improved process of machine milking and corresponding technological equipment has been carried out by Belarusian scientists, with the participation of Polish colleagues. (Treatment on scientific and technical cooperation in 2011-2016 by and between Scientific and Practical Centre of the National Academy of Sciences of Belarus for Agriculture Mechanization and Przemysłowy Instytut Maszyn Rolniczych, Poznan).

The first scientific and technical problem to be solved for the innovative modernization of machine milking process is to eliminate all factors that cause stress in animals (the release of the adrenaline into the blood, see item 2.), in other words, to ensure the *stress-free* process. As a result of analysis of the milking equipment there have been detected three causes of stress directly related to the process of machine milking: low pressure stability in the pressure vacuum circuit causing hydrodynamic injuries of the udder; hard traumatic contact of milking liner with the udder of animals; non-optimal modes of machine milking. Therefore, we have developed a new pressure vacuum circuit, significantly enhancing the stability of the expansion pressure: pressure gradient of 0.01 kPa/m, temporary instability ± 0,3 kPa, the peak amplitude of the pressure pulsations 6 kPa, pressure relaxation factor 6 kPa · s (the similar parameters in the existing pressure vacuum circuit - 0.1 kPa/m; ± 2 kPa; 45 kPa and 20 kPa · s, respectively); the upper limit of pressure in the circuit (47.8 kPa) has been substantiated, the configuration of the milking liner has been also substantiated as well as the optimum machine milking regimes have been determined basing on the election of effective speed of lactation [16-17].

The second necessary condition for increasing the efficiency of the engine of the machine milking is synchronization of machine milking time and the time of oxytocin hormone finding in the animal's blood (see item 1). The condition is associated with the importance of the choice of the time of machine milking and the action period of oxytocin. In the process of work [14] this condition is called machine milking *comfort* for the animal; it is expressed as follows:

$$t_m = t_{ox}, \quad (2)$$

where t_m – milking time; t_{ox} – oxytocin transit time in the blood of cows.

Third, and the most important condition that determines the qualitative and quantitative parameters of milk is the *completeness of the alveolar milking* (paragraphs 3 - 4). In the process of work [14] it has been found out that for the implementation of this condition there is required the velocity of machine milking to be equaled to genetically programmed speed of milk transition from the alveoli into the udder cistern:

$$v_m = v_{al}, \quad (3)$$

where v_m – machine milking rate (extraction of milk from the udder cistern into the collector), kg/min.; v_{al} – rate of milk tran-

sition from the alveoli into the udder cistern under the action of the hormone, kg/min.

If $v_m > v_{al}$, then for a short time the milk is extracted from the cistern, and when it reaches a critical milk flow rate (0.2 kg/min.), the milking machine is switched off, machine milking process is terminated, but the alveoli remain partially filled. If $v_m < v_{al}$, the overpressure increases in the cistern due to the concentration of alveolar milk therein, preventing further flow of milk from the alveoli into the udder cistern, which leads to stress and, consequently, interruption of lactation. Both cases result in incomplete alveolar milking, and as a consequence, low milk yield, low fatness, premature calving of a cow and an increased risk of mastitis.

Therefore, the milking process based on stress-free principles, comfort and completeness of the alveolar milking, is a *physiologically relaxed process* of machine milking, not injuring the animal, which favors increasing the quantity and quality of milk, and, as a result, leads to a lower level of the costs per unit in milk production.

This process comprises 2 functions: on the one hand, after all it is a process of machine milking, which must have the maximum possible performance, but on the other hand, it is a mechanized process organized in a manner to avoid its regimes to enter into a conflict with the genetic program of hormonal lactation of an animal.

How, then, can be implemented in practice, physiologically relaxed process of machine milking considering its controversial nature? It can and should be implemented on the basis of multicriteria optimization of the process. The optimization parameters that fully describe the process both from the point of view of animal health and milk production are as follow: factor Y_1 - the electric conductivity of milk (S / m), characterizes the quality of milk (fat content, somatic cell score) and animal health (even in case of asymptomatic mastitis); factor Y_2 – the lactation rate (kg/min), allows to synchronizing the time of machine milking and the active action period of oxytocin in the body of an animal; factor Y_3 – yield of milk (kg/cow/day), characterizes the productivity of animals.

As varied factors which allow to regulate the speed of machine milking, the factors have been taken whose nature is conceptually different: the expansion pressure of pressure vacuum circuit X_1 (kPa), time of pre-milking stimulation X_2 (s) and the temperature of pre-milking cattle X_3 (°C).

To study the process of machine milking there has been selected a group of 10 cows which have had the same physiological state: the 4th lactation period, calving on the 3rd – 5th February, milk productivity under the result of the third lactation period (307 days) equaled to 4.7 t/year, and the fat content of milk 3.6% (the variation of individual parameters was less than 2%). All the experimental animals were kept in loose-housing box with free access to the feed table. The machine milking has been carried out in an isolated milking room with the number of milking places 1x8. The factor Y_1, describing the health of the udder and milk quality, has been daily determined by 24 doubles (8 cows at triple daily milking); the factor Y_2, which describes the rate of lactation has been daily determined by 24 doubles; the factor Y_3 which describes the single and daily milk yield, has been daily determined by 24 and 8 doubles, respectively [14].

For cows of black-and-white breed there has been experimentally established that the milking should begin after 50-55 seconds of the manual stimulation. Experimentally, the fixed time of beginning the machine milking, is consistent with date obtained by the molecular biologists: the time of appearance of oxytocin in the mammary glands of cows of black-and-white breed after the beginning of stimulation is of ≈ 1 min. Figure 2 represents the graphs showing the dependence of the quality of raw milk and animal health Y_1, as well as the volume of raw milk from the lactation rate Y_2.

It is clearly seen that the minimum Y_1 and maximum Y_2 are achieved at the same value of the milk flow rate Y_2 =2.2 kg/min ensuring the time of milking one cow: 10.0 kg / 3 / 2.2 kg / min≈ 4.5 min, which accordingly to the literature data as per time of action of oxytocin, "squeezing out" the milk from the alveoli into the ducts and udder cistern. So, it can be affirmed that it has become possible to confirm indirectly via "technological" techniques the fact from the molecular biology, and simultaneously, the fairness of physiologically relaxed process in practice.

The fact that the speed of machine milking of 2.2 kg/min do simultaneously achieve the maximum milked milk Y_3 and the minimum of the factor Y_1 which characterizes the quality of milked milk (fatness) and the animal health (the somatic cells score), is an indirect proof that at the selected speed of machine milking there has been succeeded to synchronize the time of machine milking and the time of action of oxytocin in the body of animals. Such a coincidence confirms the fact that only ensuring the complete alveolar milking it is possible to obtain both the maximum milk yield and the maximum fat content. At the same time, in the process of milking a cow does not feel discomfort, which results in the lowest possible concentration of somatic cells (the minimum of somatic cells and the maximum of fat content gives the of $Y_1 = 0.46$, that corresponds to the Extra milk grade).

As a result of multi-criteria optimization process of machine milking, where in the kind of target function the condition is accepted which determines the high quality of milk and the health of cows $Y_1 \rightarrow$ min (stress-free), with functional restrictions of the factorY_2 (comfort of the process: milking during the action of oxytocin) and on Y_3 (completeness of alveolar milking – the factors Y_2 and Y_3 are determined depending on the physiological state of animals), there has been obtained an optimum complex of factors: x_1 = 43–45 kPa, x_2 = 46–52 s, x_3 = 8–12°C, providing physiologically gentle milking regime, which allowed to increase milk yield from 4.7 up to 5.7 t/cow/year, the fat content of milk from 3.6 to 4.1%, the share of "extra" grade of milk from 30 to 55%, with the productive longevity from 3.0 to 4.8 lactations, and to reduce the level of mastitis from 18% to 8% and, thus, create the prerequisite for realization of the genetic potential of cows [14].

The principle of multi-criteria optimization of machine milking process allows to adjust the equipment to meet the physiological characteristics of a cow that is has significance, in fact, for the other processes of feeding and keeping cows.

In order to evaluate the effectiveness of the results of both innovative and traditional modernization, we have proposed such generalized factor as *level of cost per unit*, which takes into account not only the aggregate costs, but also the quality of raw milk, as well as animal health and productive longevity, and is defined as the ratio of total cost per unit and the unit of normalized product [14, 17]:

$$\gamma = \frac{1 + n_o / n}{\alpha_M \cdot \varphi_M \cdot (1 - \delta') \cdot (1 - \delta'')} \cdot \frac{E(N_K)}{W_K \cdot N_K} \qquad (4)$$

where: γ – level of cost per unit, GJ/t; $E(N_K)/N_K$ – aggregate costs at the milk production, GJ/cow/year; N_K – number of cows.

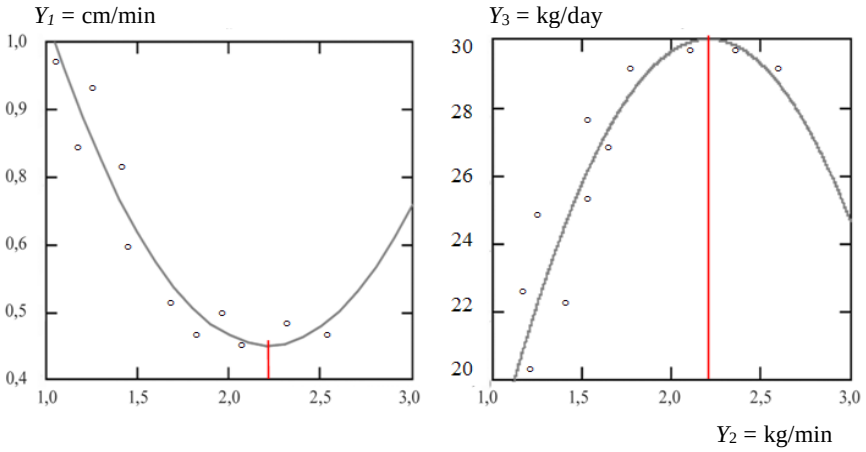

Fig. 2. The graphs of the electrical conductivity of milk Y_1 (*a*) and milking Y_3 (*б*) at the milk flow rate Y_2
[Y_1] = cm/min; [Y_2] = kg/min; [Y_3] = kg/day
Rys. 2. Wykresy przewodności właściwej mleka Y_1 (a) i dojenia Y_3 (б) przy natężeniu przepływu mleka Y_2

in the herd, heads; W_K – average yield of cows, t/cow/year; n_o – time of heifer rearing, year; n – productive longevity of cows, year; $\alpha_M = abc/a_o b_o c_o$ – milk quality factor; a, b, c – content of fat, protein, carbohydrates, respectively, kg/t; parameters of basic quality milk: a_o = 36 kg/t – content of fat; b_o = 32 kg/t – content of protein; c_o= 47 kg/t – content of carbohydrates; φ_M – coefficient of milk variety; δ' –proportion of cows which suffered mastitis; δ'' – proportion of cows with other diseases Let's note the advantage of the introduced criterion. First, it does not depend on market conditions, and does, in fact, reflect *the technological intelligence* of the dairy industry anywhere in the world. Second, in addition to the general characteristics of the dairy industry the proposed criterion characterizes the efficiency of the machine milking, as the milk production (milk yield, fat content), grade of raw milk (bacterial number, somatic cells score), bovine health (share of mastitis cows, productive longevity) are largely determined by the perfection of the process of machine milking.

The analysis of the machine milking performed by the equation (4) showed that the level of cost per unit in case of loose housing of cows with application of physiologically relaxed process of machine milking (with parameters of created process above described) equals to γ = 18,8 GJ / t, that is 2.3 times lower than the similar figure for the technology of stall barn housing with cowshed milking, and 2.2 times lower than the figure for the basic technology of loose housing with milking halls (γ = 41,4 GJ / t), which demonstrates the effectiveness of the chosen trend of innovative modernization.

4. Conclusions

1. Poland and Belarus occupy, respectively, the 16th and 21th place in the world in terms of growth of milk production and are included in the group of dairy exporting countries, allowing the countries to participate in solving important economic and humanitarian problem increasing the volumes of dairy production.
Taking into consideration the favorable climatic conditions (territories' hydrothermal factor k_H = 1,4 – 1,5), high industrial and scientific-technical potential, as well as the global shortage of dairy products, it can be affirmed that the dairy farming in Poland and Belarus should be a priority for the development of agriculture.
2. Despite high quantitative milk production (10.6 million t/year of milk in Poland and 6.7 million t/year in Belarus), the specific volume of milk produced from agricultural areas in Poland and Belarus, amounts to 80 and 78 tons/100 ha, respectively, which is 2 times lower than in Germany, although the importance of hydrothermal factor for our areas is more preferable. Thus, taking into account some distinctive features, Poland and Belarus have very similar environmental and production conditions and export opportunities for the milk industry, as well as similar scientific and technical tasks related, first of all, to reduction of costs per unit and further increase in the competitiveness of milk.
3. Currently, the most important condition for raising the dairy farming to the next level of quality is related to an innovative improvement of milk production processes via application of the all-new scientific knowledge of physiology, molecular biology and genetics to the development of technological equipment, capable to be adapted to the needs of the animal that as a result, will significantly reduce the level of costs per unit and use the genetic potential of dairy cattle breed.
4. It was shown that physiologically relaxed process of machine milking is now playing a key role in the milk production, because without reducing the total cost and proper management (stress-free, comfortable and complete alveolar milking) it is able to reduce significantly, 2-3 times , the level of the costs per unit.

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